POLARIS FBM PROGRAM
NAVIGATION SUBSYSTEM

MK 2 MOD 3 SINS, SYSTEM 2305:
PERFORMANCE CHARACTERISTICS
WITH G7B GYROS
UNDER FORCED VIBRATION (U)

Lab. Project 9500-3
Technical Memorandum 36
September 1965

TECHNICAL MEMORANDUM

U. S. NAVAL APPLIED SCIENCE LABORATORY
NAVAL BASE
BROOKLYN, NEW YORK 11251

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NAVIGATION DIVISION

Approved: ______________________
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NAVAL BASE, BROOKLYN, NEW YORK 11251

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ABSTRACT

The U.S. Naval Applied Science Laboratory is presently investigating the operational and structural vibration characteristics of the MK 2 MOD 3 SINS binnacle and stable platform assembly. This report details the forced vibration exploratory and performance runs using Autonetics G7B gyros in the system.

The binnacle and stable platform assembly had a horizontal resonant frequency of 26.1 cps and a transmissibility from the bedplate to the stable platform of 143. This low structural damping is a potential problem area due to the proximity of the resonance to the blade-excited vibration frequencies of the 627 class boats at high operating speeds. The transmissibility due to vertical inputs was essentially unity throughout the shipboard-induced vibration range.

The effect of vibration on the stable platform manifests itself as performance degrading gyro drift and jitter of the heading and attitude readouts. Resultant gyro drift rates due to forced vibration showed good correlation with those predicted using the gyro log book g^2 sensitivities. The level gyro drifts were corrected by the gyro monitor in one or more monitoring cycles subsequent to an input vibration vector change relative to the gyro axes. The Z gyro drift rate persisted throughout.

Operational MK 2 MOD 3 SINS system performance will depend on the actual shipboard vibration environment at the gyros. A survey is scheduled to be undertaken aboard the SSB(N)640 boat wherein the measurements will be taken on the stable-platform itself. This will enable an accurate definition of the vibration environment of the gyros, and an estimation of the actual degradation of system performance.

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1.0 INTRODUCTION

The U.S. Naval Applied Science Laboratory is presently investigating the operational and structural vibration characteristics of the MK 2 MOD 3 SINS, System 2305, binnacle and stable platform assembly. The sensitivity of the SINS to vibration inputs has recently assumed increased importance due to the stringent requirements imposed by the POSEIDON (C-3) program. A summary of preliminary results was presented by the Laboratory at the C-3 PDP conference held at Autonetics on 17-18 May 1965. The summary, in addition to the follow-up work decided upon at the conference, was reported in reference (b). This report details this phase (Phase "Two", see section 2.0) of the evaluation.

2.0 TEST PLAN

Reference (a) outlined a test program for investigating the vibration characteristics of the MK 2 MOD 3 SINS binnacle and stable platform assembly. The evaluation was divided into three phases. The first and third phases entailed no vibration, and consisted of various calibration, electrical zeroing and gimbal axis bearing friction measurements to be performed before and after the vibration phase of the evaluation. Phase one has been accomplished and will be reported upon completion of phase three. The first portion of phase 2 (operations with G7B gyros), reported herein, includes forced vibration tests of exploratory, performance determination, and diagnostic nature.

3.0 EQUIPMENT AND INSTRUMENTATION

3.1 The binnacle and stable platform assembly was overhead mounted to an "A" frame support. The vibration table, to which the "A" frame was mounted, is an L.A.B. 2500 lb. capacity, reaction type machine which is capable of horizontal or vertical single frequency sinusoidal inputs. The complete assembly is shown in Figure 1.

3.2 Optical mirrors mounted on the "A" frame (Location A), the Azimuth Plate or "stalk" mirror (Location B) and the Train Axis Optical Cube (TAOC) (Location C) were monitored by three autocollimators as shown in Figure 2. The two lower units are conventional autocollimators and the remaining unit is an electronic device whose outputs are a function of angular rotation in tilt and azimuth.

3.3 Eighteen M.B. Type 120 and 124 vibration pickups were used to monitor the respective vibrations on the "A" frame, the stable platform (hat) and the vibration table. The pickup locations are shown in figure 3. The vibration data was recorded on a C.E.C. recording oscillograph having a 26 channel capacity. The system analog readouts of velocity, position and attitude were monitored on Sperry dual channel, and Brush recorders.

3.4 The stable platform was carefully balanced and servo loop gains reset before starting this phase of the evaluation. Autonetics MK 2 MOD 2 (G7B) gyros were used throughout. The system was then tested, fully operational, in the various gyro stabilized modes.

4.0 VIBRATION CHARACTERISTICS

4.1 Ringing

The assembly was manually shock excited, in a horizontal, athwartships direction, and the output of the horizontal pickup on the "hat" was recorded. The response was an exponentially damped sinusoid of 27 cps with a decay time constant of 1.4 seconds. Based upon the simplifying assumption that the assembly is essentially a second order system, the following calculations were made:

Damping Ratio $\xi = \frac{1}{\tau 2\pi f_n} = 0.0042$

Transmissibility at Resonance $Q = \frac{1}{2\xi} = 119$

Where: τ = time constant (seconds)
f_n = horizontal natural frequency (cps)

4.2 Forced Horizontal (Athwartships) Vibration

4.2.1 Under forced vibration, the maximum measured horizontal transmissibility from the bedplate to the "hat" was 143 at 26.1 cps with an input g level of 0.005g. The entire vibration characteristic from 10 to 35 cps is presented in Figure 4. Superimposed on the same graph are the corresponding input "g" levels. The dip at resonance is due to the loading characteristics of the vibration machine when operating at these minute input levels. The angular vibration of the bedplate and the stable platform were negligible, but Roll and Azimuth inductosyn transmission errors of 80 and 20 arc seconds, respectively, occurred at resonance, due to flexure within the SINS structure.

4.2.2 Two additional Transmissibility curves are plotted in figure 5. These are the transmissibility (T) characteristics from the bedplate to the Donut and to the bearing unit. The dip of T to less than unity just before resonance is attributed to bending of the Donut, reference (e).

4.2.3 The first-order, blade excited frequency due to a 627 class submarine propeller operating at maximum speed is 24.5 cps, based on a 7 blade propeller rotating at 210 RPM:

$$210 \frac{\text{Rev}}{\text{Min}} \times \frac{\text{Min}}{60 \text{ Sec}} \times 7 \frac{\text{Cycles}}{\text{Rev}} = 24.5 \text{ cps}$$

As shown in Figure 3, a horizontal transmissibility of 8.4 was measured at 24.5 cps. The corresponding Roll and Azimuth transmission errors were 24 and 5 arc seconds, respectively.

4.2.4 The SINS' velocity outputs (10 knots/rev-CX) to the fire control interface were recorded during the vibration runs. The vibration frequency was not discernible in the velocity outputs.

4.3 Forced Vertical Vibration

A vertical resonance search from 5 to 35 cps was conducted. The results are presented in figure 7. Vertical inputs of 0.04g yielded approximately unity transmissibility throughout the shipboard blade-excited range. Some low Q torsional resonance phenomena occurred at 30 cps. The transmitted Azimuth error at this frequency was 20 $\widehat{sec}$ peak to peak. A rocking resonance about the Roll axis was observed at the "ringing" frequency of 27 cps which induced a transmitted roll error of 25 $\widehat{sec}$ and a horizontal translation at the hat of 0.24g.

5.0 DIAGNOSTIC INVESTIGATIONS

5.1 At the C-3 PDP conference of 17-18 May 1965, the Laboratory summarized the system sensitivities to vibration thus far observed. At that time, the actual resonant frequency and transmissibility had not yet been determined under forced vibration. Due to the extremely high Q present, the system was being preserved, by limiting the g level at the stable platform to 0.5 maximum, until sufficient system/component performance data was obtained.

5.2 At the conference, the Laboratory agreed to remove and examine the existing set of shockmount frangible pins. This was to check for possible damage which may have resulted in the indicated lower resonant frequency than that previously observed by the contractor, reference (f). It was also agreed to attempt to close the resonance curves and determine the actual Q and fo at the lowest practicable vibration input level.

5.3 The following is a summary of the results:

a. A control vibration run, with the original set (No. 1) of frangible pins installed, was performed. The stable platform g level was limited to 0.5 and resonance was avoided.

b. A new set (No. 2) of pins was installed and a vibration run under identical conditions as the control run was performed. The results were remarkably identical to those of the control run.

c. The vibration table input was then reduced and a resonance search was attempted. The maximum transmissibility recorded was 46 at 25.8 cps, but was observed to be rapidly decreasing with time. At the 2 to 2.5 g maximum level achieved at the stable platform, an apparent structural yield had occurred but total failure was not evident.

d. A complete run from 5 to 35 cps was then performed and produced the stable resonance characteristic of Q and f_o equal to 29.5 and 25 cps respectively.

e. Microscopic examination of the frangible pins of Set No. 1 and Set No. 2 showed small cracks. The installation and removal of a third set without any interim vibration also produced small cracks.

f. Solid Tooling pins were installed in all positions, and replaced one at a time with frangible pins. The vertical alignment was preserved at all times and monitored with dial gauges. (Set No. 4)

g. A vibration characteristic from 5 to 35 cps was obtained and observed to be stable with a Q and f_o of 35 and 25.1 cps, respectively.

h. Solid Tooling pins were installed and produced a stable resonance characteristic with a Q and f_o of 29.6 and 25.6 cps, respectively.

i. The binnacle was inspected to determine whether any member had failed or shaken loose and was causing the reduced Q and f_o, while vibrating at the higher platform g levels. It was found that two balance weights inside the stable platform had become loose. After correcting this condition, the resonance search was resumed.

j. With the Solid Tooling pins, a horizontal athwartships vibration characteristic from 5 to 35 cps was obtained and observed to be stable with a Q and f_o of 120 and 26.3 cps, respectively.

k. A new set (No. 5) of frangible pins was installed using the technique of paragraph 5.3(f). The horizontal vibration characteristic achieved was again stable with a Q and f_o of 143 and 26.1 cps respectively. The curve (Figure 4) has the same shape as those obtained previously with the original sets of frangible pins.

6.0 PERFORMANCE CHARACTERISTICS

Damped Inertial Mode performance runs were included in the evaluation. To facilitate detection of systematic effects, the runs were generally 23 hours long. The first 8 and last 7 hours were used as control portions wherein the system navigated in a non-vibratory environment. The system was subjected to forced vibration in the mid-8 hour period.

6.1 Operating Conditions

6.1.1 Vibration input levels were in the range of 0.04 to 0.05 gs for both the Athwartships and Vertical directions at frequencies of 23.5, 24.0 and 24.5 cps. These vibration input levels were designated so as to limit the g level at the stable platform to a maximum of 0.5 g.

6.1.2 Autonetics MK 2 MOD 2 (G7B) gyros were used in the system during the performance runs. Three gyro configurations were used in all, and were as follows:

SET	X	Y	Z	M
A	7410-21	7077-11	7186-21	7022-11
B	7186-21	7077-11	7410-21	7022-11
C	7186-21	7410-21	7077-11	7022-11

The system's Gyro Monitor was recalibrated after installation of each gyro configuration.

6.1.3 Nineteen 23 hour runs were performed at various stable platform alpha angles and vibration levels. The binnacle heading was 270° throughout. Prior to the start of each run, the Z gyro was biased by two-fix reset. The level gyros were automatically biased every hour by the system's gyro monitor.

6.2 Performance FOMs

Figure 7 is a tabulation of the 8 hour time RMS Azimuth, Latitude and Longitude errors of the initial control and vibration portions of the individual performance runs. Also listed are the corresponding input vibration data.

6.3 System Axis Drift Rates

The system axis drift rates were determined by hourly two-fix reset calculations, performed using overlapping two-hour fix intervals for each run. The mean of each segment (8 hours control —8 hours vibration—7 hours control) was determined and then used to establish the drift rate change due to the vibration input.

6.3.1 Changes of the residual level axis drift rate of up to 0.4 and 0.2 MDH were observed upon application and removal of horizontal and vertical vibration, respectively. Tabulated below is a composite of all the horizontal and all the vertical vibration runs. Presented are the mean and standard deviation of the drift rates for the first control and vibration periods.

	8 HR CONTROL PERIOD $\bar{x}$	σ	8 HR VIBRATION PERIOD $\bar{x}$	σ
HORIZONTAL				
Wx(MDH)	0.01	0.25	0.14	0.26
Wy(MDH)	0.32	0.45	0.08	0.35
VERTICAL				
Wx(MDH)	-0.15	0.10	-0.17	0.10
Wy(MDH)	0.56	0.17	0.66	0.14

A change in the residual level axis drift rates constitutes an effective change in the gyro monitor calibration during the vibrated interval. Although small, these changes, when observed, were systematic and the calibration reverted to the original value upon removal of the vibration. An increase in level axis noise during vibration was not evident throughout the runs.

6.3.2 Z axis drift rate changes of up to 2.5 and 0.2 MDH were observed upon application and removal of horizontal and vertical vibration, respectively. Unlike the level axes, the Z axis is not monitored and so the drift rate remained throughout the period of vibration. The drift rate returned to its original level after the vibration was removed.

6.4 Z Gyro Sensitivity to Vibration was determined for inputs along the spin axis (SA) and output axis (OA) and at 45° to both the spin and output axes. This was accomplished by plotting the drift rate changes versus g^2 (at the gyro) for each platform alpha angle. The best straight line was drawn through the points and the slope of this line is the sensitivity in millidegrees/hr/g^2 (MDH/g^2). The following is a tabulation of the above results.

Z GYRO SENSITIVITY (MDH/g^2)

ALPHA ANGLE:		0°	45°	90°
VIBRATION PARALLEL TO:		SA		OA
7077	G7B-11	*	19.5	*
7186	G7B-21	-5.0	12.0	7.0
7410	G7B-21	-7.5	8.5	*

* No data available.

6.5 Level Gyro Sensitivity to Vibration

The system level axis drift rates, as computed by two-fix reset, are not directly indicative of the level gyro drift rates in a monitored system. To de-

termine the actual gyro sensitivity to vibration, the gyro drift rate before and during vibration had to be reconstructed by removal of the cumulative gyro monitor bias corrections.

6.5.1 The procedure and formulas used to reconstruct the level gyro drift rates were derived in reference (c) and are as follows:

$$\epsilon_x = W_x - \sum \Delta b_{xm}$$

$$\epsilon_y = W_y - \sum \Delta b_{ym}$$

$$\epsilon_m = -\sum \Delta b_{mx}, \; -\sum \Delta b_{my}$$

where: $\epsilon_x, \epsilon_y, \epsilon_m$ = X, Y, M Gyro Reconstructed Drift Rates

W_x, W_y = Residual X, Y Axis Drift Rates

$\sum \Delta b_{xm}, \sum \Delta b_{ym}$ = Commulative Monitor X, Y gyro bias corrections

$\sum \Delta b_{mx}, \sum \Delta b_{my}$ = Cumulative Monitor self bias corrections in the X,Y position.

6.5.2 Level gyro drift rate changes of up to 4.5 millidegrees/hour (MDH) were observed upon application and removal of Athwartships vibration. The maximum changes occurred at vibration inputs at 24.5 cps in directions 45° to the platform X and Y axes. Under these conditions, the transmissibility is approximately 10 and the vibration acts along the level gyro's major compliance axes, reference (f). The maximum drift rate change for vertical vibration was 0.5 MDH. In all cases the changes in drift rates were systematic and returned to the original levels when the vibration was removed.

6.5.3 Level gyro sensitivity to vibration was determined for inputs along the spin axis (SA) and the input axis (IA) and at 45° to both the spin and input axes. As in the case of the Z gyro, the reconstructed drift rate changes were plotted as a function of g^2 (at the gyro) for each platform alpha angle. The best straight line was drawn through the points and the slope (sensitivity) determined. The following is a tabulation of the above results in MDH/g^2.

LEVEL GYRO SENSITIVITY (MDH/g^2)

VIBRATION PARALLEL TO:		IA	45° to IA & SA	SA
7022	G7B-11	5.3	15.0	7.8
7077	G7B-11	0.5	-25.0	1.5
7186	G7B-21	13.5	36.5	-
7410	G7B-21	2.0	26.0	8.0

6.6 GYRO COMPLIANCE COEFFICIENTS

Gyro sensitivity to vibration results from vibratory displacements of the center of mass of the gyro float with respect to its center of support caused by anisolelastic constraint. This displacement acts synchronously with the inertia force on the float, to result in a net or rectified torque on the float proportional to the square of the applied vibratory acceleration. The relationship between the compliance torque and the applied vibration vector is derived in reference (j). From this general equation, the specific expressions for induced platform gyro drift rates were derived from Horizontal Athwartships vibration.

6.6.1 Gyro Sensitivities to Athwartships Vibration

$$\frac{Wx}{a^2} = \frac{B_2}{2} \text{SIN } 2(H-\alpha) + \frac{A_2}{2} [1-\text{COS } 2(H-\alpha)] - \frac{Kis}{2} \text{COS } 2(H-\alpha)$$

$$\frac{Wy}{a^2} = \frac{B_2}{2} \text{SIN } 2(h-\alpha) - \frac{A_2}{2} [1+\text{COS } 2(H-\alpha)] + \frac{Kis}{2} \text{COS } 2(H-\alpha)$$

$$\frac{Wz}{a^2} = \frac{Kso}{4} \text{SIN } 2(H-\alpha) - \frac{Kis}{4} [1-\text{COS } 2(H-\alpha)]$$

where:

Wx, Wy, Wz	X, Y, Z gyro drift rates
a	Peak acceleration due to vibration
A_2	Minor Compliance coefficient
B_2	Major Compliance coefficient
Kso/2	Cross Compliance coefficient
Kis/2	
H	Ships Heading
α	Stable Platform Heading

The symbols in the above equations are those used in the gyro log books.

6.6.2 The gyro drift rate sensitivities determined during the Damped Inertial Mode runs were substituted into the above equations and the compliance coefficients were calculated. The following is the tabulation of the calculated coefficients along with the values determined from Tumble Test Data. The Autonetics' numbers are those recorded in the gyro log books. The Laboratory performed the Tumble Test subsequent to the vibration runs.

GYRO COMPLIANCE COEFFICIENTS (MDH/g^2)

GYRO S/N	COMPLIANCE COEFFICIENT	SYSTEM DATA	TUMBLE TEST DATA LABORATORY	TUMBLE TEST DATA AUTONETICS
	A_2	-2.0	-1.5	9.7
7077	B_2	-52.0	-50.7	-68.2
	Kso/2	37.5	18.5	0.5
	Kis/2	-1.5	—	—
	A_2	18.5	3.1	3.3
7186	B_2	54.5	52.3	31.0
	Kso/2	29.0	5.8	20.5
	Kis/2	5.0	—	—
	A_2	9.8	2.8	1.0
7410	B_2	52.0	32.8	46.4
	Kso/2	24.8	4.6	23.1
	Kis/2	7.8	—	—

7.0 DISCUSSION OF RESULTS

7.1 The system response to manual shock excitation in the horizontal athwartships direction was a damped oscillation of 27 cps. The damping ratio and Q were calculated to be 0.0042 and 119, respectively. Prior experience with systems of such low structural damping indicates that persistant "ringing" may occur, in service, due to repetitive shock inputs, despite the apparent absence of vibration input at the natural frequency. These shock inputs can be caused by wave motion during surface operations or by extreme maneuvers.

7.2 The resonance search under forced horizontal Athwartships vibration yielded a Q of 143 at 26.1 cps. The results show good correlation with those of the ringing method, especially since the calculation of Q from the ringing data assumes that the assembly is a second order linear system, which is a rough approximation, considering the actual complex structure.

7.3 The maximum transmissibility of 3.6 under forced vertical vibration occurred at 30 cps. The transmissibility below 27 cps was substantially unity. Thus, the forced vertical vibration effects may be considered of secondary importance.

The cause of the excitation of the horizontal rocking resonance observed with vertical input, was not established. The residual horizontal output of the vibration table, when in the vertical mode, was within the noise level of the in-

strumentation. Excitation of the high Q horizontal mode by this source, could not therefore be separated from the possibility of elastic or mass asymmetry effects along the support and vibration axes.

7.4 The figure of merit (FOM) of the Damped Inertial mode runs (figure 7) were generally within the specification values, reference (g), for both the 8 hour control portion and the vibrated portion of the runs at the vibration levels chosen. However, the relative performance was considerably degraded in the vibrated portion. The average increase in the FOM was 300, 470 and 550% for Azimuth, Latitude and Longitude errors, respectively, for the horizontal runs. Corresponding average increases in FOM for the vertical runs were 180, 230 and 120% for Azimuth, Latitude and Longitude errors, respectively.

The gyro monitor corrected both its self and the platform level gyro drift rates in one or more one-hour monitoring cycles subsequent to an input vibration vector change (either magnitude, frequency or (H-α) change). Limiting of the gyro monitor corrections may cause undue delay in correcting larger drift rate changes. The Z gyro drift persisted throughout the vibration and returned immediately to the original level upon removal of the input vibration. The monitored level gyros, having been compensated, see the negative of the original disturbance, when the vibration ceases, which again must be monitored out in one or more cycles.

The SINS error propagation of a typical 23 hour performance run is shown in Figure 8. The vibration input was horizontal and athwartships, with a magnitude and frequency of 0.04g and 24 cps, respectively.

7.5 The compliance coefficients calculated from the resultant G7B gyro drift rates showed good correlation with the g^2 sensitivities determined from tumble tests, section 6.5.2, considering that the tumble test results are accurate to only ± 8 MDH/g^2, reference (d). Thus, using the equations of section 6.5.1 for athwartships vibration, gyro drift rate changes can be reasonably estimated using the compliance coefficients as listed in the gyro log books if the input vibration vector is known.

8.0 CONCLUSIONS

8.1 The MK 2 MOD 3 SINS binnacle and stable platform assembly has a horizontal resonant frequency of 26.1 cps with a maximum transmissibility of 143 from the bedplate to the stable platform. This low structural damping is a potential problem area due to the proximity of the resonance to the blade-excited vibration frequencies of the 627 class boats at high operating speeds. The transmissibility due to vertical inputs is essentially unity throughout the shipboard induced vibration range and so is not considered significant.

8.2 The effect of a vibration input manifests itself as performance degrading gyro drift and jitter of the heading and attitude readouts. The resultant gyro drift rates show good correlation with those predicted using the gyro log book g^2 sensitivities. The level gyro drifts are corrected by the gyro monitor in one or more monitoring cycles subsequent to an input vibration vector change relative to the gyro axes. The Z gyro drift persists throughout the vibrated interval. The actual degradation of system performance will depend on the shipboard environment at the gyros.

8.3 The vibration inputs used during this investigation have been held at the lowest levels possible with the available instrumentation. Although performance under these conditions has been within the A-3 requirements, nevertheless Z gyro drift rate changes of up to 2.5 MDH have been observed. Such drift rate changes would constitute a major and significant error source for the C-3 system.

8.4 At a conference, at the Electric Boat Division of General Dynamics Corporation in Groton, Connecticut, on 18 June 1965, it was decided to place vibration pick-offs on the stable platform as well as the bedplate of one MK 2 MOD 3 SINS in the forthcoming vibration survey aboard the SSB(N)640 boat. This will enable an accurate definition of the vibration environment of the gyros and an estimation of the actual degradation of system performance.

9.0 PRESENT STATUS

The Laboratory is presently evaluating MK 2 MOD 3 SINS operation with Nortronics MK 5 MOD 6 (V7) gyros under the same vibration environments as reported herein.

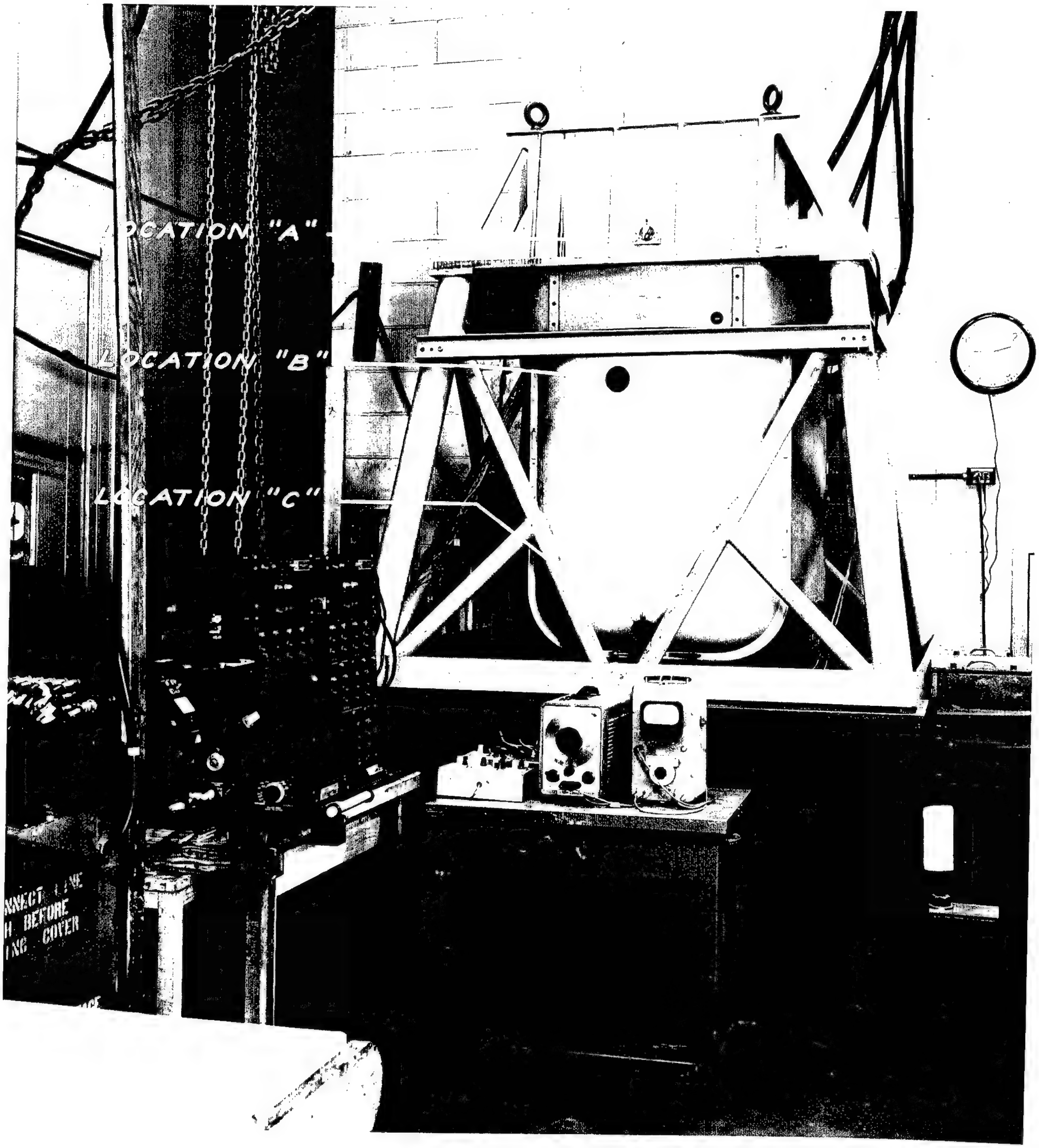

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Figure No. 1

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MK 2 MOD 3 SINS, SYSTEM 2305 BINNACLE
VIBRATION TABLE and TEST INSTRUMENTATION

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PHOTO 20034-1

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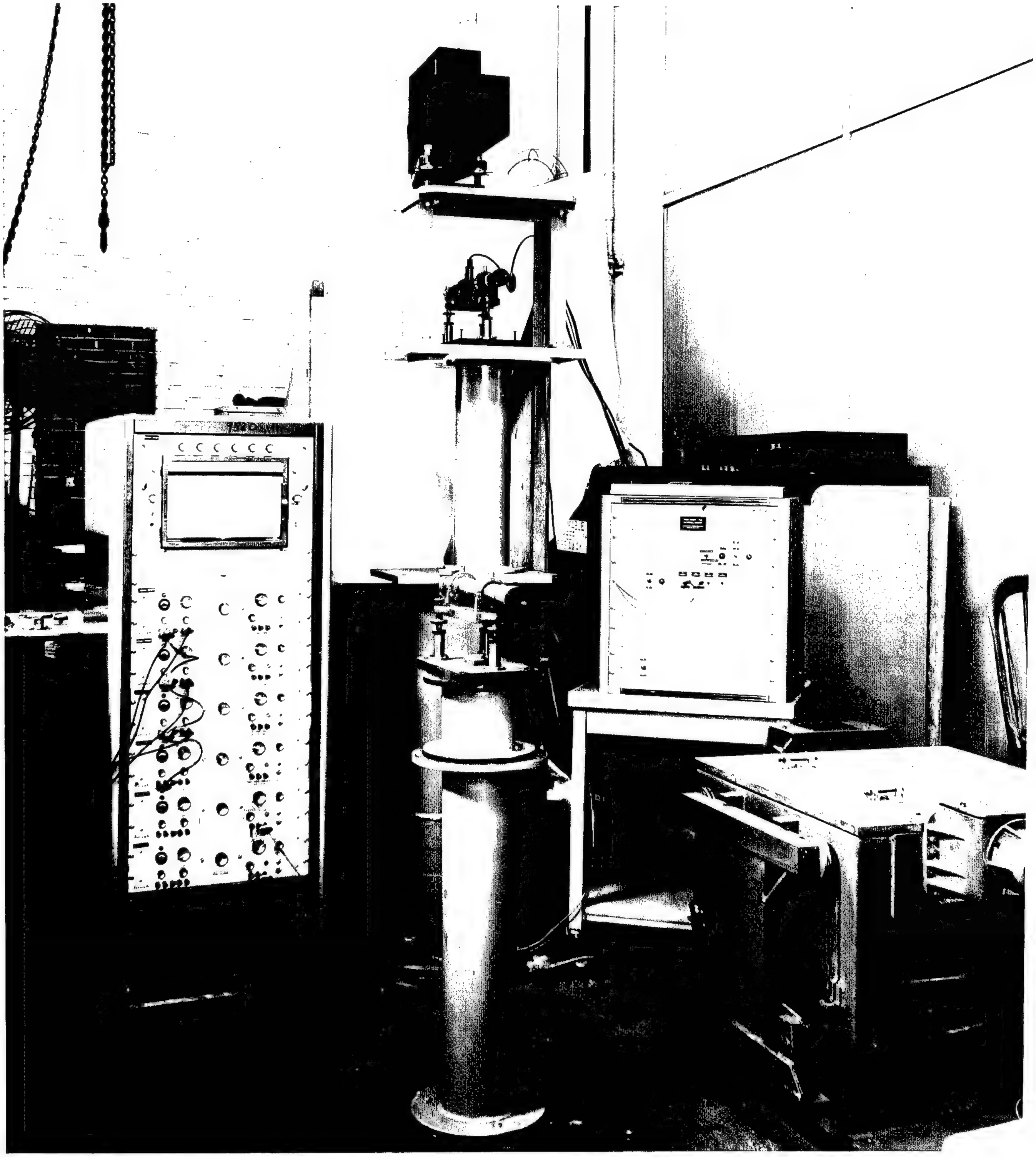

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Figure No. 2

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AUTOCOLLIMATORS and TEST INSTRUMENTATION

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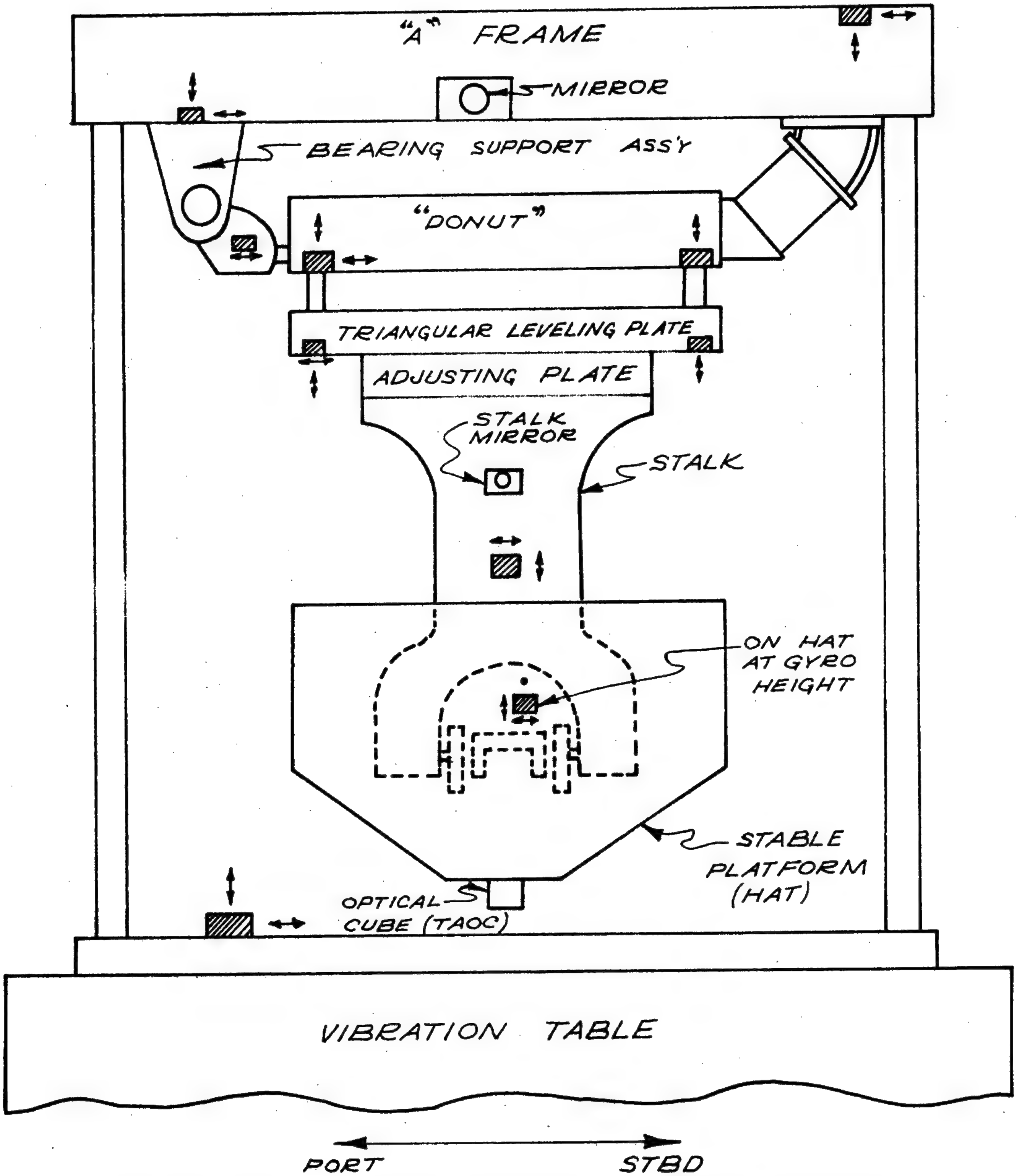

LOCATION OF VIBRATION PICKUPS ON N7F STABLE PLATFORM ASSEMBLY, SHOCKMOUNT STRUCTURE, & TEST FIXTURE

NOTE: INPUT AXES OF PICKUPS WILL BE ORIENTED ALONG AXIS OF VIBRATION.

LEGEND:
▨ VIBRATION PICKUPS

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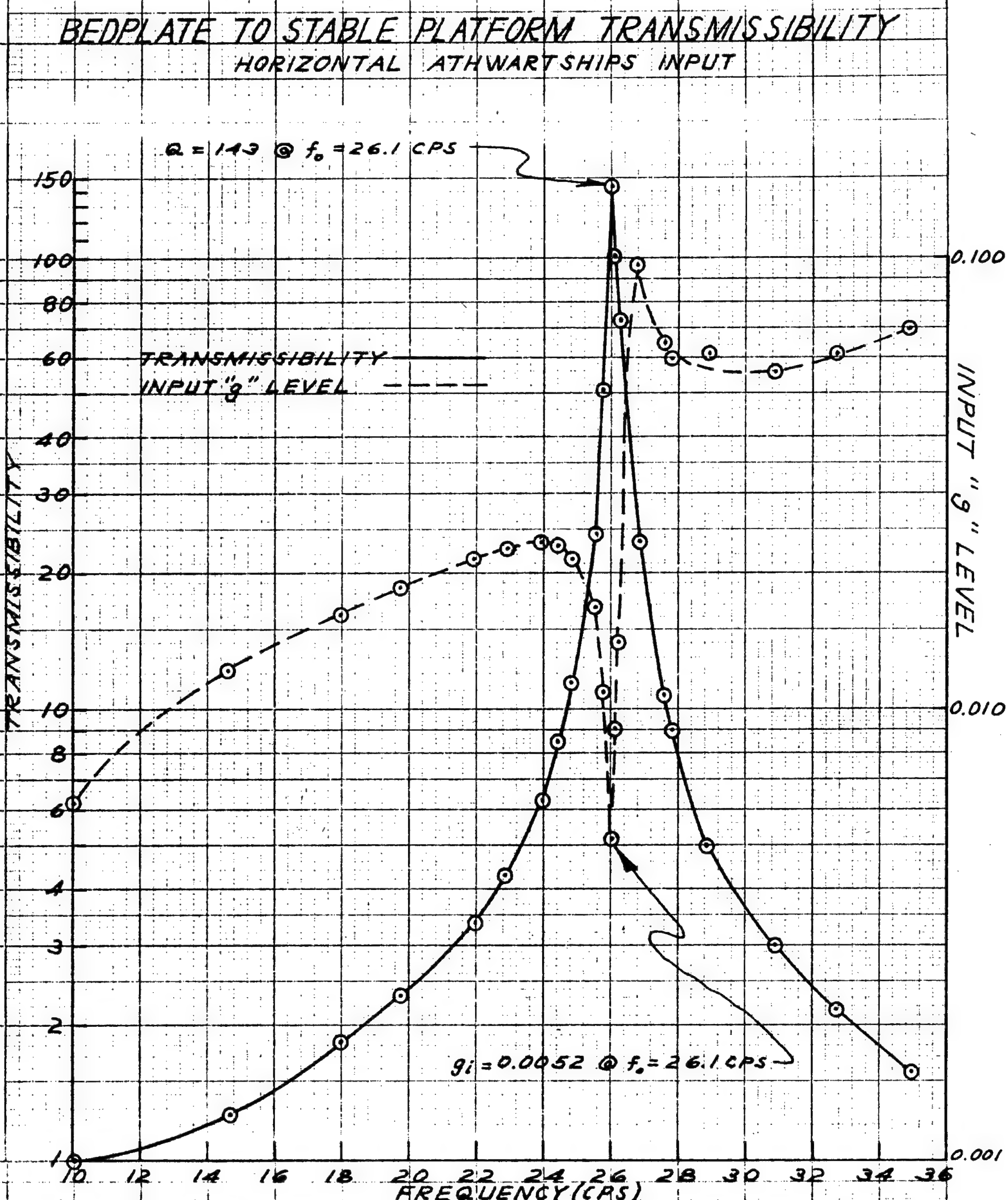
FIGURE NO. 3



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SYSTEM 2305
2 JUNE, 1965

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FIGURE NO. 4

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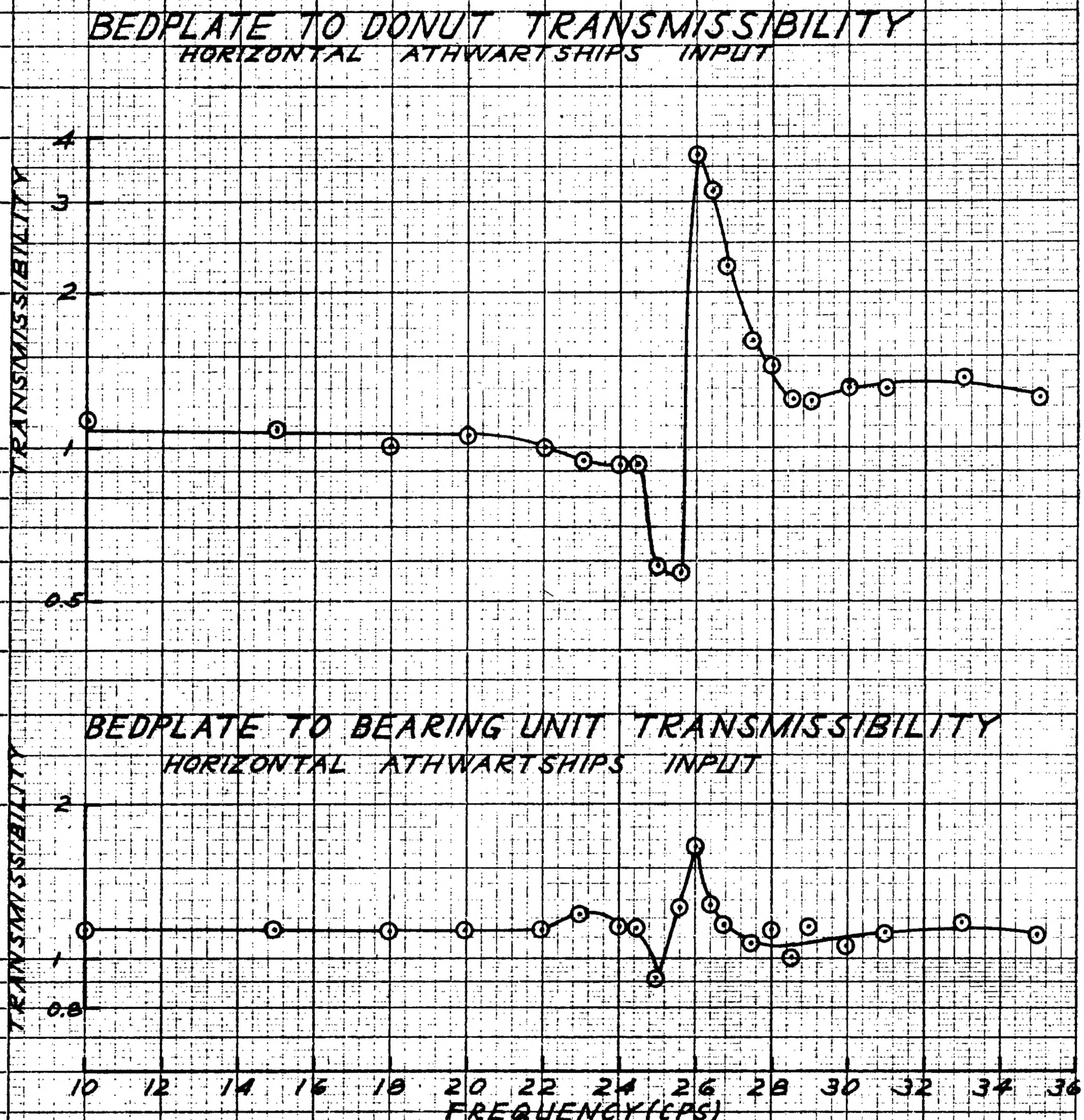

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FIGURE NO. 5

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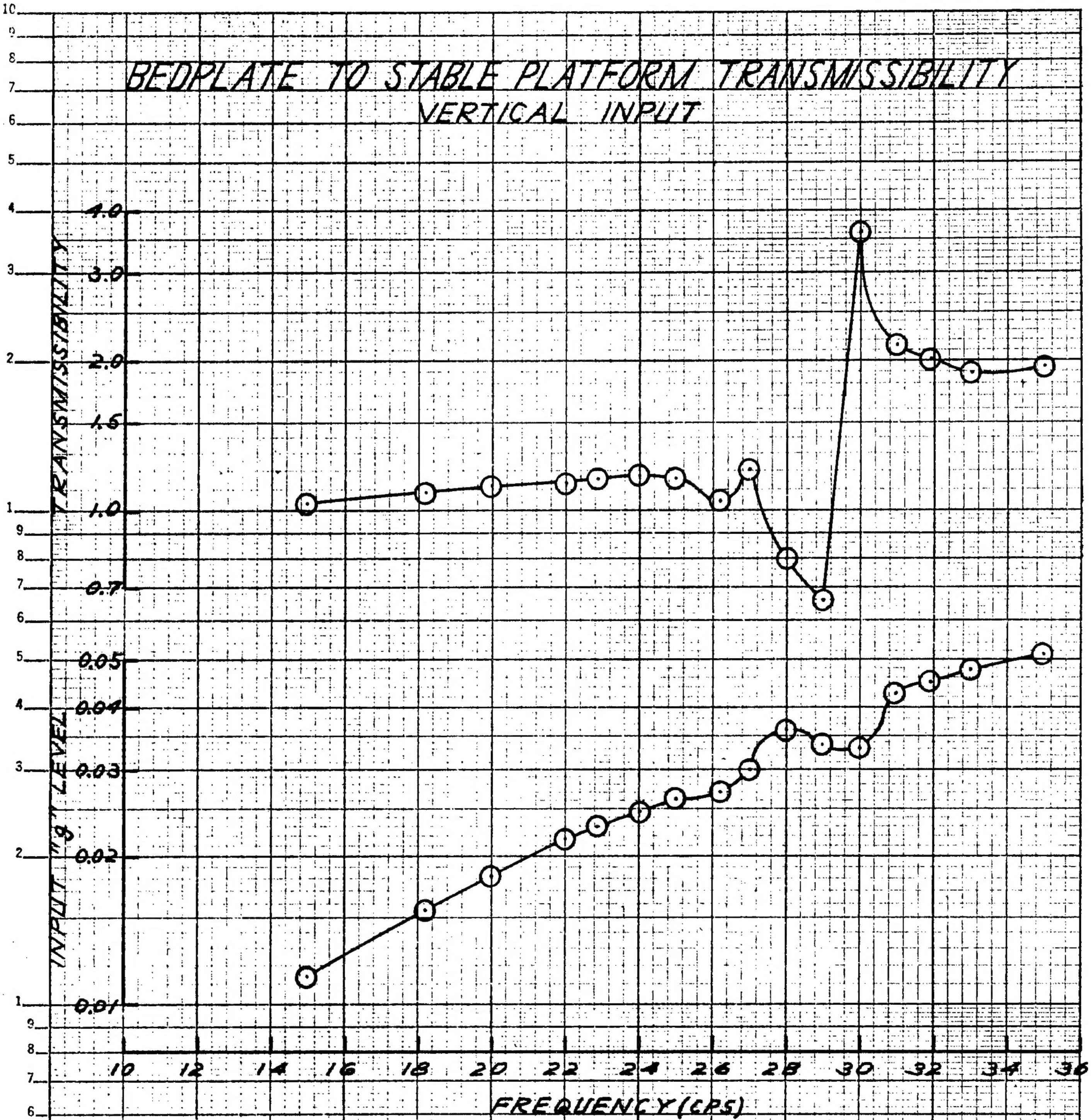

MK 2 MOD 3 SINS

SYSTEM 2305

APPLIED SCIENCE LABORATORY

LAB. PROJECT 9500-3 TECH. MEMO NO. 36

FIGURE NO. 6

FIGURE 7: SYSTEM PERFORMANCE FOMs UNDER VIBRATION

HORIZONTAL ATHWARTSHIPS VIBRATION

Gyro Set	Alpha Angle	Vibration		T	8 Hr Control			8 Hr Vibration		
		Freq cps	Input g		AZM Sec	Lat. N.Mi.	Long. N. Mi.	AZM Sec	Lat. N. Mi.	Long. N. Mi.
A	0°	23.5	0.041	5.68	3	0.11	0.02	20	0.09	0.05
A	0°	24.0	0.041	7.09	6	0.16	0.05	26	0.14	0.12
A	0°	24.5	0.040	9.36	18	0.09	0.02	41	0.60	0.38
A	45°	23.5	0.041	5.95	8	0.02	0.05	15	0.08	0.13
A	45°	24.0	0.040	7.67	5	0.03	0.07	12	0.19	0.07
A	45°	24.5	0.039	9.58	4	0.01	0.10	6	0.20	0.10
A	90°	23.5	0.040	6.08	3	0.02	0.02	7	0.21	0.04
A	90°	24.0	0.040	7.63	1	0.02	0.01	2	0.18	0.07
A	90°	24.5	0.039	9.95	7	0.12	0.05	9	0.12	0.16
B	0°	23.5	0.042	5.74	13	0.16	0.04	37	0.22	0.19
B	0°	24.5	0.041	9.33	21	0.12	0.01	41	0.33	0.29
B	45°	23.5	0.041	6.40	14	0.05	0.14	16	0.09	0.07
B	45°	24.0	0.042	7.24	30	0.15	0.08	18	0.43	0.54
B	45°	24.5	0.040	10.32	12	0.10	0.18	5	0.11	0.10
C	45°	23.5	0.053	5.43	2	0.07	0.05	22	0.25	0.12
C	45°	24.5	0.053	7.04	5	0.11	0.04	12	0.30	0.15
		560 SPEC			43	0.47	0.41			

VERTICAL VIBRATION

A	0°	23.5	0.044	1.21	14	0.10	0.12	22	0.19	0.13
A	0°	24.0	0.046	1.19	14	0.09	0.13	17	0.20	0.17
A	0°	24.5	0.049	1.32	9	0.07	0.09	24	0.12	0.12
		560 SPEC			43	0.47	0.41			

UNCLASSIFIED

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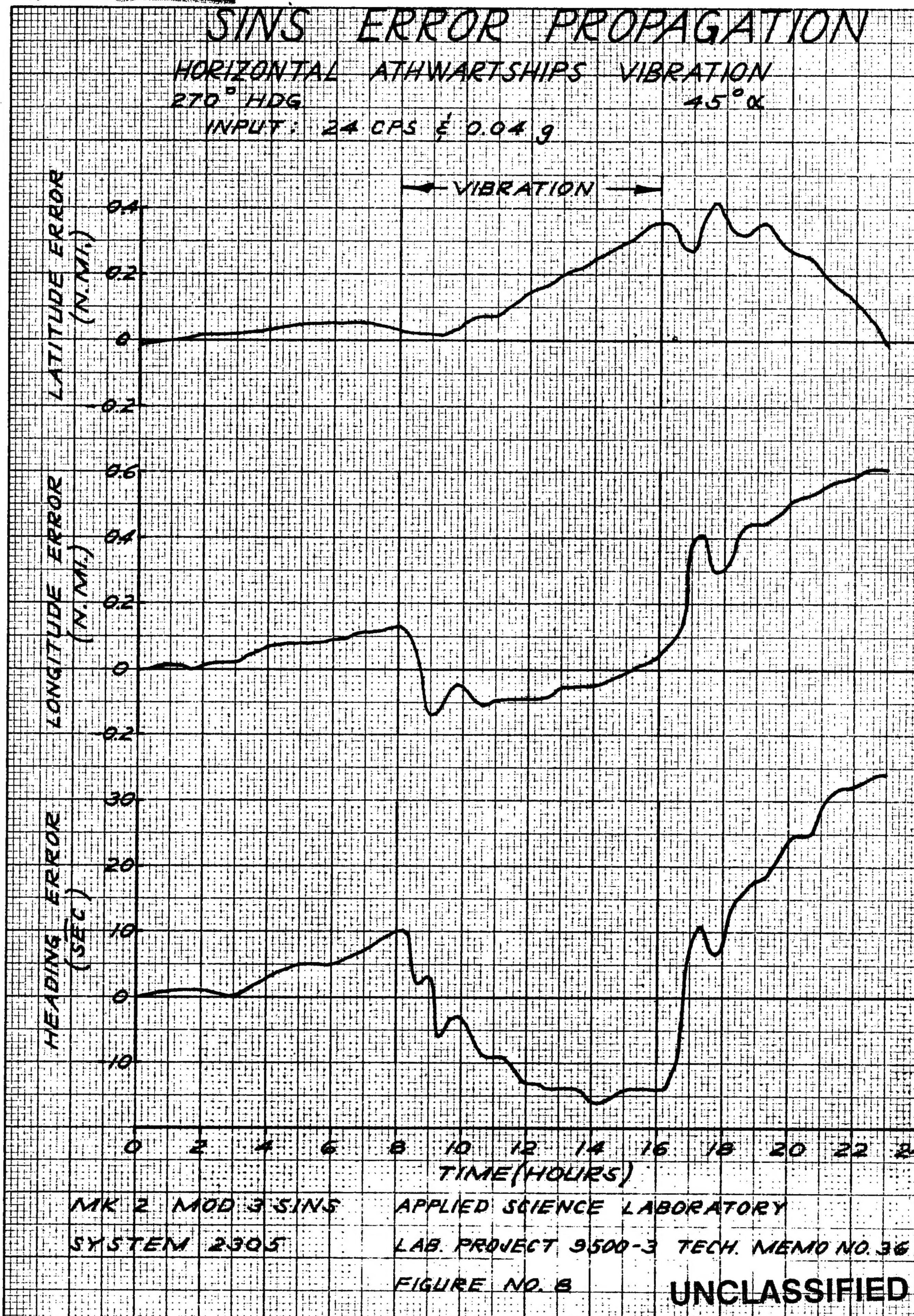

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